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Physical and combustion properties of briquettes from sawdust of *Azadirachta indica*

O. A. Sotannde • A. O. Oluyege • G. B. Abah

Abstract: The study was undertaken to investigate the properties of cassava starch and gum arabic bonded briquettes from the sawdust of *Azadirachta indica*. The briquettes were produced using a Jack press at an average pressure of 10.7 kg·cm^{-2}. The sawdust and binders were mixed at ratios of 100:15, 100:25, 100:35 and 100:45 in weight, respectively. The briquettes produced were subjected to physical and combustion tests. Both the physical and combustion properties of the briquettes vary with binder types and binder levels ($p < 0.05$). The result shows that briquettes bonded with starch gave better performance based on density of 0.546 g·cm^{-3}, durability rating of 95.93%, heating value of 33.09 MJ·kg^{-1}, percentage of fixed carbon of 84.70% and low ash and volatile matter of 3.35% and 11.95%, respectively, while briquette bonded with gum arabic has density of 0.425 g·cm^{-3}, durability rating of 94.85%, heating value of 32.76 MJ·kg^{-1}, percentage of fixed carbon of 87.30% and low ash and volatile matter of 4.45% and 8.75, respectively. Since the aim of briquetting is to produce briquette that will serve as a good source of fuel and support combustion, the best briquette was produced when the sawdust-starch ratio and sawdust-gum arabic ratio was 100:25 and 100:35, respectively.

Keywords: *Azadirachta indica*; briquette; binder level; durability rating; combustion properties

Introduction

One of the major challenges facing Sub-Saharan African (SSA) countries particularly in the sudano-sahelian region is the energy

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demand. Traditionally, wood in form of fuel wood, twigs and charcoal has been the major source of renewable energy for many developing countries. Although Africa accounts for 12% cent of the global population, it consumes only 4% of global energy (Ardayfio-Schandorf 1996). Within the continent, the rate of consumption varies. For example in Nigeria, renewable energy accounts for 51% of the total energy consumption (Akinbami 2001). Similarly, in Kenya, the current annual supply of fuelwood is estimated to be 18.7×10^6 tonnes which accounts for 73% of total energy consumption (Kituyi et al. 2001).

The high and rapidly increasing demand for wood fuel consumption is considered as a major contributing factor to the fuelwood crisis in Sub-Sahara Africa (Himraj 1993). Due to this crisis and considering that rural households have to continue meeting their cooking energy requirements, attention has been drawn on the need to consider alternative sources of energy supply. Such energy sources should be renewable and accessible to the poor. As rightly noted by Stout and Best (2001), a transition to a sustainable energy system is urgently needed in the developing countries such as Nigeria. One energy source is wood waste or sawmills residues. Briquette making has the potential to meet the additional energy demands of urban and industrial sectors, thereby making a significant contribution to the economic advancement of developing countries. However, in order to make a significant impact as a fuel source, there is a need to improve and promote its technology of production (Grover et al. 1994). The technology may be defined as a densification process for improving the handling characteristics of raw material and enhancing the volumetric calorific value of the biomass (Wilaipon 2007). For achieving the desired success, the briquette Press should be inexpensive, simple and easy to repair. While much attention has been focused on cutting of trees and shrubs to meet the fuel energy needs, many wood residues come out of wood-based industries that are of little economic value. Wood process residues constitute about 10% to 75% of the log input depending on the end product (Hakkila et al. 2002). These residues, if properly harnessed, could contribute to sustainable fuel energy requirement.

This study was aimed at producing briquettes from the sawdust of *Azadirachta indica* A. Juss. using gum arabic and starch

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as binding agents. The effect of binder level in sawdust-binder mix on the physical and combustion properties were investigated. This study became necessary in view of the recent interest in the use of *A. indica* for timber production. Thus, the study seeks to find a productive way of utilizing sawdust during the conversion of the wood in sawmills.

Materials and methods

Raw material preparation

The trees of *A. indica* were felled from a plantation within University of Maiduguri, in the north-eastern part of Nigeria. The stems and branches were cut into billets and processed in the school wood workshop for determining strength properties while the sawdust generated in the process was used for this study. The dust was dried in air and thereafter its moisture content was determined. The cassava starch used as binding agent was purchased from the market while the gum arabic was residue obtained during the process of grading it for sale. The gum arabic was sieved to remove impurity and thereafter grinded. The press consists of wooden frame fitted with hydraulic jack (Dahlam et al. 2001). The mould was made from a PVC pipe of 28 cm long with an inner diameter of 10.4 cm. Holes were drilled on the pipe to about one third of the height, so that water can drain easily when the briquette is pressed (Dahlam et al. 2001). Two pieces of wooden disks were cut with a diameter slightly smaller than the inner diameter of the PVC pipe and were used as lids to cover both ends of the pipe during molding.

Briquette production and quality evaluation

For each batch of briquette, 100g of dried sawdust was mixed with either cassava starch or gum arabic   until a uniform mixture was obtained. The proportions of binder in the mixture were 15%, 25%, 35%, and 45%. Thus, the component ratio (sawdust: binder) in each charge for briquetting were 100:15, 100:25, 100:35 and 100:45. The sawdust-binder mixture was then hand-fed into the PVC pipe that served as a mould and covered at both ends with the wooden disk. The sawdust-binder mix inside mould was later placed under the press and compacted at a pressure of 10.70 kg·cm^{-2}, and was kept under pressure for 5 minutes. At each level of binder, 15 replicates were produced. The diameter of the briquettes was thereafter taken at two different points with the aid of digital calipers while the weight and thickness were also recorded immediately.

Physical properties determination

For physical properties determination, four briquettes were randomly selected from each production batch for evaluation. The mean compressed density of the briquettes was determined immediately after removal from the mould as a ratio of measured weight to calculated volume (Olorunnisola 2007). To determine dimensional stability, the length of four representative briquettes

was measured at 0, 30, 60 and 1440 and 10,080 min intervals. Equilibrium moisture contents (E.M.C) of the briquettes after 19 days of sun-drying were determined at an ambient temperature of (22±3)ºC and relative humidity of (75 ± 5)%, respectively. The relaxed density and relaxation ratio of the briquettes were also determined in the dry condition after 19 days.

The durability of the briquettes was determined in accordance with the chartered index described by Suparin et al. (2008). The briquette samples were dropped repeatedly from a specific height of 1.5 m onto a solid base (metal plate). The fraction of the briquette retained was used as an index of briquette breakability. The durability rating of the briquette was expressed as a percentage of the initial mass of the material remaining on the metal plate.

Combustion properties determination

The combustion properties include percentage of volatile matter, fixed carbon, ash content and heating value. The percentage of volatile matter, fixed carbon and ash contents of four representative samples were determined based on ASTM Standard E711-87 (2004). For percentage of volatile matter, 1g of the briquette was placed in a crucible of known weight and oven dried to constant weight after which it was heated in the furnace at temperature of 600 ºC for 10 minutes. The percentage of volatile matter was then expressed as the percentage of loss in weight to the oven dried weight of the original sample. The percentage of ash content followed the same procedure with volatile matter except that the sample was heated in the furnace for 3 hours. The ash content obtained after cooling in a dessicator was then expressed as percentage of the original sample. The percentage of fixed carbon was calculated by subtracting the value of the addition of percentage of volatile matter and percentage of ash content from 100%. This is expressed in the equation below:

$$C = 100 - (V + A) \qquad (1)$$

where, *C* is the percentage of fixed carbon, *V* is the percentage of volatile matter, and *A* is the percentage of ash.
Heating value was calculated by using this Gouthal formula:

$$H_v = 2.326(147.6C + 144V) \qquad (2)$$

where, H_V is the heating value (MJ·kg^{-1}), *C* is the percentage of fixed carbon, and *V* is the percentage of volatile matter (Bailey et al. 1982).

Results and discussion

Compressed density and relaxed density

One of the major indices for assessing the combustion and handling characteristics and ignition behavior of briquettes is density. It could be in form of compressed density (density determined

immediately after compression), relaxed density (density determined when dried) and relaxation ratio (ratio of compressed density to relaxed density). The influence of binder type, binder level and their interaction had a marked effect on the compressed and relaxed density of the briquettes (Table 1). However, the type of binder used does not influence the relaxation ratio (p = 0.056). The average compressed density (0.546 g·cm^{-3}) in briquettes bonded with starch was higher than that in briquettes bonded with gum arabic (0.425 g·cm^{-3}). The implication of this is that starch had more gluing strength than gum arabic. This was clearly evident that there was a higher relaxation ratio for briquettes bonded with gum arabic. When the binder level was varied, it was discovered that an inverse relationship existed between briquette density and relaxation ratio. The optimum value was reached when 25% of the binders were used. This trend confirms the influence of binder level and binder type on briquette density (Wilaipon 2007). Thus, the higher the density, the lower the relaxation ratio of the briquette will be and the better the stability of the briquette. Overall, compressed density obtained in both briquette types was less than the range of 0.98 to 1.12 g·cm^{-3} reported for bio-coal briquettes under moderate pressure (Wilaipon 2008).

Table 1. The average density, relaxed density and relaxation ratio of the briquettes

| Variables	Compressed density (g·cm^{-3})	Relaxed density (g·cm^{-3})	Relaxation ratio
Binder type			
Gum arabic	0.425±0.04*	0.355±0.07	1.20±0.22
Starch	0.546±0.17	0.464±0.06	1.18±0.14
Binder level (%)			
15	0.361±0.02^{c}**	0.310±0.07^{c}	1.16±0.22^{a}
25	0.542±0.17^{a}	0.523±0.04^{a}	1.04±0.16^{bc}
35	0.525±0.14^{b}	0.484±0.06^{b}	1.08±0.10^{b}
45	0.352±0.01^{c}	0.302±0.06^{c}	1.17±0.23^{a}
Binder effect[†]			
Gum arabic (%)			
15	0.331±0.01	0.291±0.04	1.14±0.07
25	0.435±0.04	0.414±0.02	1.05±0.12
35	0.420±0.03	0.381±0.05	1.10±0.04
45	0.363±0.01	0.322±0.03	1.12±0.06
Starch (%)			
15	0.362±0.01	0.322±0.02	1.13±0.05
25	0.643±0.08	0.613±0.07	1.05±0.06
35	0.641±0.17	0.600±0.08	1.07±0.07
45	0.360±0.02	0.310±0.03	1.16±0.06
Significance level			
Binder type	p = 0.001	p = 0.0241	p = 0.056
Binder level	p = 0.001	p = 0.001	p = 0.001
Binder effect	p = 0.001	p = 0.001	p = 0.001

Notes: * Mean and standard deviation of 4 replicate samples. ** Values with the same alphabet in each column are not significantly different at α = 0.05 using Duncan multiple range test. [†] Interaction due to binder effect.

Briquette stability

The briquette stability was measured in terms of its dimensional changes when exposed to the atmosphere. The briquette with minimum dimensional changes is said to be stable. It has been established that briquettes and or pellets compressed in a closed cylinder have a tendency to expand as the pressure is released (Olorunnisola 2007). The expansion takes place primarily in the direction in which the load is applied. Figs 1 and 2 show the increase in length of the briquettes with time. The observed linear expansions were generally minimal. Briquettes produced with 25% of the binder in both cases were observed to be most stable. Based on this, it could be inferred that the briquette produced with 25% of the binders produced the most stabilizing effect. This confirms that stability of the briquette is a function of the binder levels and density often produced (Bruhn et al. 1959).
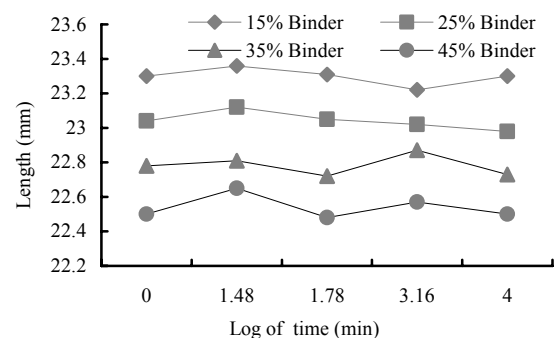
Fig. 1   Linear expansion of briquette bonded with gum arabic over time
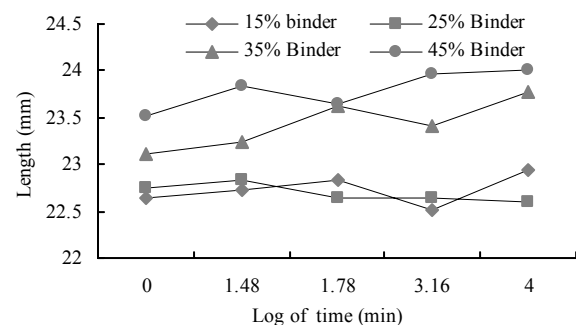
Fig. 2   Linear expansion of briquette bonded with starch over time

Equilibrium moisture content (E.M.C.)

As shown in Table 2, the E.M.C. of the briquettes bonded with gum arabic was higher than that of briquettes bonded with starch. The variation in binder level and interaction between binder type and binder level significantly influenced the E.M.C of the briquettes ($p < 0.05$). The equilibrium moisture content did not follow a particular pattern when the binder level was varied. It ranged between 2.50% and 6.76% in briquettes bonded with gum arabic and between 2.59% and 3.58% in briquettes bonded with starch. This value is below the range of 12%–20% reported by

Wamukonya and Jenkins (1995) on sawdust and wheat straw briquettes. The difference could be as a result of the nature of the material and difference in climatic condition since equilibrium moisture content is a function of relative humidity and temperature of the surrounding air. The low E.M.C. is expected to influence the durability and storability of the briquettes.

Durability rating

The result of analysis of variance presented in Table 2 shows that binder type, variation in binder level and binder effect significantly influenced the durability rating of the briquettes. Durability rating (95.93%) in briquette bonded with starch was higher than that in briquettes bonded with gum arabic (94.85%). The reason for this might be due to the higher gluing strength of starch as exemplified by higher compressed density of briquettes bonded with starch over briquettes bonded with gum arabic . Durability rating was also observed to increase with increase in binder level. It increased from 90.27% to 98.31% in gbriquettes bonded with gum arabic and from 91.12% to 99.42% in briquettes bonded with starch. Thus, it could be inferred that durability of a briquette is a function of moisture content, density (Hussain et al. 2002) and variation in binder level. Increase in density and binder level enhances durability while moisture content reduces (Olorunnisola 2007).

Table 2. The equilibrium moisture content and durability rating of the briquettes

Variables	E.M.C. (%)	Durability rating (%)
Binder type		
Gum arabic	4.56±2.27*	94.85±3.44
Starch	3.07±1.07	95.93±3.38
Binder level (%)		
15	4.50±2.26[a]**	92.65±1.91[c]
25	2.79±0.41[b]	95.86±1.18[b]
35	3.07±1.37[b]	98.21±0.67[a]
45	4.90±2.23[a]	94.85±5.22[b]
Binder effect[†]		
Gum arabic (%)		
15	6.41±1.20	90.28±2.88
25	2.56±0.11	94.18±1.24
35	2.50±0.15	96.64±0.59
45	6.76±1.51	98.31±0.59
Starch (%)		
15	2.59±0.98	91.12±0.92
25	3.58±1.88	95.09±1.13
35	3.08±0.38	98.10±0.81
45	3.04±0.47	99.42±0.86
Significance level		
Binder type	$p = 0.001$	$p = 0.015$
Binder level	$p = 0.001$	$p = 0.001$
Binder effect	$p = 0.001$	$p = 0.001$

Notes: * Mean and standard deviation of 4 replicate samples. ** Values with the same alphabet in each column are not significantly different at $\alpha = 0.05$ using Duncan multiple range test. [†] Interaction due to binder effect.

Percentage of volatile matter

The result in Table 3 shows that binder type, binder level and

their interaction significantly influenced the volatile matter of the briquettes with p– values of 0.002, 0.023 and 0.007, respectively. The volatile matter (11.95%) in briquettes bonded with starch was higher than that of briquettes bonded with gum arabic (8.75%). When the binder level was increased, it was observed that percentage of volatile matter also increased. It increased from 7.0% to 10.0% in briquettes bonded with gum arabic and from 7.60% to 16.0% in briquettes bonded with starch. The increase in percentage of volatile matter with increase in binder level might be attributed to higher content of the binder in the mixture ratio. However, the values obtained for the two binders fell within the smokeless fuel grade. The fuel related to smokeless grade is known to contain no more than 20% volatile substances (Ivanon et al. 2003), so they can be considered as smokeless fuel. Also, the low percentage of volatile matter is an indication that the ignition rate will be low, since high volatile matter enhanced sporadic burning of the fuel.

Percentage of fixed carbon

The percentage of fixed carbon in briquettes bonded with gum arabic was slightly higher than that of briquettes bonded with starch (Table 3). When the binder level was varied, the highest percentage of fixed carbon was obtained at 25% binder level. However, the value of 88.10% for fixed carbon at 25% binder level was not significantly different from the value of 87.40% at 15% binder level but differed significantly from value at 35% and 45% binder levels. Thus, the percentage of the binder in the mixture ratio plays a significant role in the percentage of fixed carbon of the resultant briquette. The value in this study compared favorably with the briquette properties of some tropical trees. It is expected that the high percentage of fixed carbon and its smokeless flame will enhance the heat value and combustion duration of the briquette.

Percentage of ash content

The result of the percentage of ash content of the briquettes in Table 3 shows that the difference in binder type and binder level had a marked effect on the ash content of the briquette ($p < 0.05$). The briquettes bonded with gum arabic has higher ash content than briquettes bonded with starch. It ranged from 3.40% to 5.80% in briquettes bonded with gum arabic and from 2.40% to 4.40% in briquettes bonded with starch. The low values of ash content obtained could be due to the high heating value of the two briquette types. Ash content in the briquette normally causes increase in the combustion remnant in form of ash which lowers the heating effect of the briquette.

Heating value

The heating value in briquettes bonded with starch (33.09 MJ·kg^{-1}) was slightly higher than that in briquettes bonded with gum arabic (32.76 MJ·kg^{-1}). When the binder level was varied, the highest heating value was obtained when 25% of the binder was used with a heating value of 33.19 MJ·kg^{-1}, but this value

was not significantly different from 32.92 MJ·kg^{-1} and 33.03 MJ·kg^{-1} of heating values when 15% and 35% of the binder was used respectively. The heating value ranged from 32.27 MJ·kg^{-1} to 33.08 MJ·kg^{-1} in briquette bonded with gum arabic and from 32.57 MJ·kg^{-1} to 33.42 MJ·kg^{-1} in briquette bonded with starch (Table 3). The heating values of the two briquette types were found to be higher than 18.89 MJ·kg^{-1} obtained in banana peel briquette (Wiliapon 2008), 14.1 MJ·kg^{-1} obtained in maize cob briquette (Wiliapon 2007), 24–27 MJ·kg^{-1} for lignites with bio-binder (Ivanov et al 2003). Thus, making sawdust briquettes from *Azadirachta indica* shows a good potential for domestic cooking.

Table 3. Combustion properties of the briquettes

Variables	Volatile matter (%)	Fixed carbon (%)	Ash (%)	Heating Value (MJ·kg^{-1})
Binder type				
Gum arabic	8.75±2.22*	87.30±3.39	4.45±1.50	32.76±0.56
Starch	11.95±4.85	84.70±5.64	3.35±1.66	33.09±0.34
Binder level (%)				
15	8.70±2.63^b**	87.40±3.31^{ab}	3.90±1.29^b	32.92±0.57^a
25	8.80±2.10^b	88.10±2.51^a	3.10±0.99^b	33.19±0.21^a
35	11.90±3.78^a	84.60±75^{bc}	3.50±1.43^b	33.03±0.63^a
45	12.00±5.87^a	82.90±7.31^c	5.10±2.18^a	32.42±0.93^b
Binder effect†				
Gum arabic (%)				
15	7.00±2.74	89.00±3.67	4.00±1.00	33.02±0.52
25	8.00±2.74	88.60±1.36	5.80±1.74	33.08±0.39
35	10.00±0.01	85.40±1.14	3.40±1.14	32.67±0.39
45	10.00±0.01	84.20±1.14	4.60±1.14	32.27±0.62
Starch (%)				
15	7.60±2.51	89.60±2.70	2.80±0.84	33.31±0.21
25	10.40±0.94	87.20±2.70	2.40±0.55	33.42±0.17
35	13.80±4.82	82.40±5.36	3.80±1.64	32.91±0.57
45	16.00±5.48	79.60±6.73	4.40±2.51	32.69±0.93
Significance level				
Binder type	$p = 0.002$	$p = 0.050$	$p = 0.022$	$p = 0.057$
Binder level	$p = 0.023$	$p = 0.069$	$p = 0.025$	$p = 0.010$
Binder effect	$p = 0.007$	$p = 0.026$	$p = 0.434$	$p = 0.484$

Notes: * Mean and standard deviation of 4 replicate samples. ** Values with the same alphabet in each column are not significantly different at $\alpha = 0.05$ using Duncan multiple range test. † Interaction due to binder effect.

Conclusions

The results from this study have shown that a satisfactory briquette can be produced from sawdust of *A. indica*. The quality of the briquettes was influenced by the type and level of binder used. A direct relationship was observed between briquette density, stability and durability rating. Briquette with higher density was observed to have higher stability and durability rating and low relaxation ratio. Similarly, briquette with high percentage of fixed carbon and heating value has low volatile matter and ash content. The bonding strength of starch was higher than that of gum arabic. Thus, the quality of briquette bonded with starch

was higher than that of briquette bonded with gum arabic. As a final conclusion from this study, the best strategy for producing briquette from *A. indica* wood residue would include pressing a blend of its sawdust with cassava starch at a ratio of 100:25 (100g sawdust with 25g cassava starch) in weight. Alternatively, a blend of the sawdust with gum arabic at a ratio of 100:35 (100g sawdust with 35g gum arabic) will also produce a satisfactory briquette.

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